

BRANONS AS DARK MATTER *

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In the brane-world scenario with low tension, brane fluctuations (branons) together with the Standard Model particles are the only relevant degrees of freedom at low energies. Branons are stable, weakly interacting, massive particles and their relic abundance can account for the dark matter of the universe. In a certain range of the parameter space, they could be detectable by future direct search experiments.

1. Brane fluctuations: branons

In the brane-world scenario our universe is understood as a 3-dimensional brane embedded in a D -dimensional space-time ($D = 4 + N$). The fundamental scale of gravity in D dimensions M_D is no longer the Planck scale M_P , but can be much lower, and the tension of the brane $\tau = f^4$ fixes a completely independent energy scale ¹.

In this context, new fields appear on the brane. On one hand, we have the Kaluza-Klein modes of the gravitons propagating in the D -dimensional bulk space, and on the other, the fields which describe the brane fluctuations. These fields are called branons and they are the Goldstone bosons associated to the spontaneous breaking of the translational invariance in the extra dimensions induced by the presence of the brane ^{2,3}. But, in general, translational invariance is not an exact symmetry of the bulk space, i.e: branons can acquire a mass M ⁴. If $f \ll M_D$ (low tension), KK gravitons decouple from the SM particles ⁵, and therefore, at low energies, only SM particles and branons are important.

The SM-branon low-energy effective Lagrangian was obtained in ⁶ and it reads:

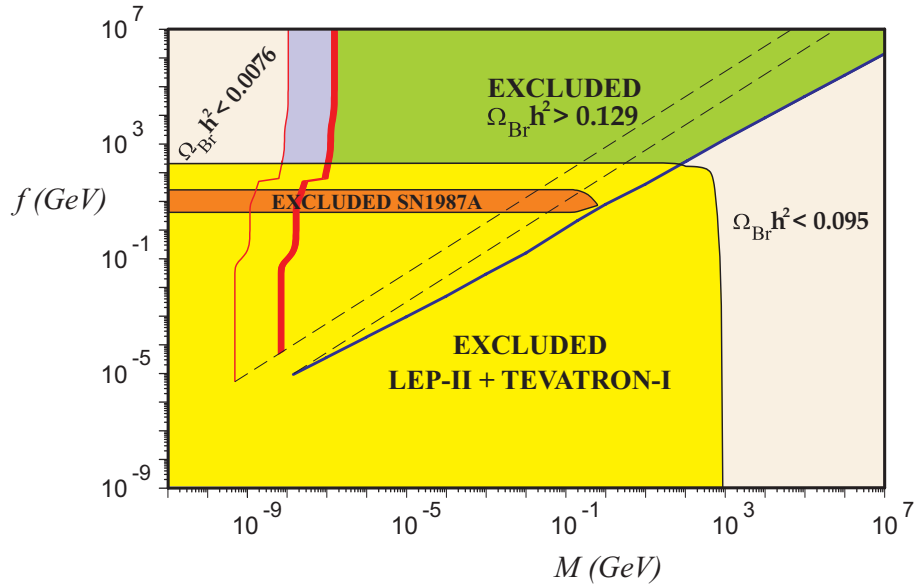
$$\begin{aligned} \mathcal{L}_{Br} = & \frac{1}{2} g^{\mu\nu} \partial_\mu \pi^\alpha \partial_\nu \pi^\alpha - \frac{1}{2} M^2 \pi^\alpha \pi^\alpha \\ & + \frac{1}{8f^4} (4\partial_\mu \pi^\alpha \partial_\nu \pi^\alpha - M^2 \pi^\alpha \pi^\alpha g_{\mu\nu}) T_{SM}^{\mu\nu} \end{aligned} \quad (1)$$

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We see that branons interact by pairs with the SM energy-momentum tensor. This means that they are stable particles. On the other hand, their couplings are suppressed by the brane tension f^4 , i.e. they are weakly interacting. These features make them natural dark matter candidates ^{7,8} (see ⁹ for a recent review on dark matter).

2. Branons as dark matter

When the branon annihilation rate, $\Gamma = n_{eq}\langle\sigma_A v\rangle$, equals the universe expansion rate H , the branon abundance freezes out relative to the entropy density. This happens at the so called freeze-out temperature $T_f = M/x_f$. We have computed this relic branon abundance in two cases: either relativistic branons at freeze-out (hot-warm) or non-relativistic (cold), and assuming that the evolution of the universe is standard for $T < f$ (see Fig. 1).



Relic abundance in the $f - M$ plane for a model with one branon of mass: M . The two lines on the left correspond to the $\Omega_{Br}h^2 = 0.0076$ and $\Omega_{Br}h^2 = 0.129 - 0.095$ curves for hot-warm relics, whereas the right line corresponds to the latter limits for cold relics (see ¹⁰ for details). The lower area is excluded by single-photon processes at LEP-II ^{6,11} together with monojet signal at Tevatron-I ¹². The upper area is also excluded by cosmological branon overproduction ¹⁰. The astrophysical constraints are less restrictive and they mainly come from supernova cooling by branon emission ¹⁰.

3. Detecting branons

If branons make up the galactic halo, they could be detected by direct search experiments from the energy transfer in elastic collisions with nuclei of a suitable target. For the allowed parameter region in Fig. 1, branons cannot be detected by present experiments such as DAMA, ZEPLIN 1 or EDELWEISS. However, they could be observed by future detectors such as CRESST II, CDMS or GENIUS.

Branons could also be detected indirectly: their annihilations in the galactic halo can give rise to pairs of photons or e^+e^- which could be detected by γ -ray telescopes such as MAGIC or GLAST or antimatter detectors (see ¹³ for an estimation of positron and photon fluxes from branon annihilation in AMS). Annihilation of branons trapped in the center of the sun or the earth can give rise to high-energy neutrinos which could be detectable by high-energy neutrino telescopes such as AMANDA, IceCube or ANTARES. These searches complement those in high-energy particle colliders (both in e^+e^- and hadron colliders) in which real (see Fig. 1) and virtual branon effects could be measured ^{14,6,12}.

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